PATENT SPECIFICATION

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(54) METHOD FOR RECOVERING VISCOUS OIL FROM A NATURALLY FRACTURED FORMATION AND OIL RECOVERED BY SUCH METHOD

(71) We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V., a company organized under the laws of the Netherlands, of 30, Carel van Bylandtlaan, The Hague, the Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention is concerned with a method for recovering viscous oil from a naturally fractured formation, particularly a limestone formation, and oil recovered by such method. Such formation comprises permeable blocks, for example, limestone blocks surrounded by a fracture network that has been created by natural phenomena. The fracture network as well as the permeable pore space of the blocks contain viscous oil. Such naturally created fracture networks often occur in limestone formations.

It will be appreciated that viscous oil can be recovered from such formation at very low rates only, since the viscous oil will move very slowly through the fractures. Further, this viscous oil will be almost immobile in the pore space of the blocks, as the pore space has even a lower permeability than the fracture network. Any attempts to displace such viscous oil from a naturally fractured formation by a displacement process applying liquid or steam that is injected into such formation for displacing or driving the oil towards a production well will fail, since the injected fluids will bypass the pore space of the blocks and proceed directly from the injection wells to the production wells via the fracture network, thereby displacing only the contents of this network. Since the amount of oil present in the fracture network does not represent a significant part of the total amount of oil present in the formation, such drive process is not very effective.

The oil recovery method according to the invention relates in particular to the recovery of oil having a viscosity higher than 100 centipoises under the conditions existing in the formation prior to carrying out the present invention therein.

According to the present invention a method for recovering oil from a formation comprising permeable blocks surrounded by a natural fracture network, said formation containing oil in the fracture network and in the pore space of the blocks, said oil having a viscosity higher than 100 centipoises, includes the steps of:

a) displacing oil from the fracture network in at least one region of the formation by injecting a fluid into that region via a well communicating with the fracture network in that region;

b) circulating hot aqueous fluid through the fracture network in the said region to increase the temperature of the oil-containing blocks in that region;

c) recovering oil via at least one production well during steps a) and b);

d) stopping the circulation of hot aqueous fluid and replacing this fluid in the fracture network by a gas under pressure;

e) allowing drainage of oil from the pore space of the blocks in said region into the gas-containing fractures in said region;

f) collecting drained oil in the lower part of the fractures in said region, and

g) recovering oil from this lower part of the said region via a well communicating with the fractures in said region.

The fluid injected in step a) of the present method may substantially consist of steam, a gas, or a liquid. When applying liquid for displacing the oil from the fracture network, this liquid may substantially consist of water that has a temperature either lower or higher than the original temperature of the formation.

Further, the hot aqueous fluid that is circulated through the fracture network in step b) of the present method may substantially consist of water having a temperature higher than the original temperature of the formation, or substantially consist of steam, or be a mixture of steam and water having a temperature higher than the original temperature of the formation.

The gas under pressure applied in step d) of the present method may substantially consist of air that is kept stagnant in the fracture network of the formation. Instead of air, natural gas may be used. However, application of the present method is not limited to the use of air or natural gas in step d). Other gases may be applied as well. The use of non-condensable gases is in particular attractive in formations where high pressures prevail in the fracture network. In case of a low pressure in the fracture network, steam may be applied. Also, steam may be added to the gas under pressure for compensating heat losses occurring in the formation.

It is observed that the present method may be applied in formations (such as limestone formations) wherein the natural fracture network may be of any pattern. Also, the application of the present invention is not restricted to formations wherein oil is the only fluid present in the pore space of the blocks and in the fracture network. With equal results, the present method may be applied in formations wherein water is present in combination with oil. This water may be connate water (which is distributed over the formation) or be bottom water (which is only present in the lower part of the formation).

In fact, three oil recovery stages can be distinguished during application of the method according to the present invention. In the first stage, oil will be displaced towards recovering wells by the fluid that is injected to remove the viscous oil in the part of the fracture network extending between injection and recovery wells, thereby creating an oil-free passage between injection and recovery wells, through which passage hot aqueous fluid can be circulated in the second stage of the method. Once such passage has been formed, hot aqueous fluid is circulated therethrough to increase the temperature of the oil-containing blocks that are adjacent to this fluid passage. During this second stage, oil will be expulsed from the pore space of the blocks by thermal expansion of the oil content of these blocks, and/or by the formation of oil vapour bubbles. Also, the mobility of the oil will be increased since the viscosity thereof will be reduced by the temperature increase. As a result thereof, part of the oil will be displaced from the pore space by the difference between the specific densities of the oil and the aqueous fluid. An additional amount of oil may be recovered by reducing the pressure in the fracture network to a value lower than the value of the pressure originally prevailing therein. Thus, extra oil will flow into the heated part of the fracture network by expansion of the oil present in the pore space of the blocks. Further, oil will flow from the unheated part of the fracture network to the heated part thereof. Finally, the third stage of the oil recovering method substantially coincides with the period in which the fracture network contains pressurized gas. Gravity drainage will then be the primary factor influencing the recovery of oil from the pore space of the limestone blocks, since the relatively large difference between the specific gravities of the heavy oil present in the pore space of the blocks and the gas present in the fracture network will be sufficient to allow the oil with reduced viscosity to flow readily out of the pore space of the blocks. This oil will then flow downwards through the gas-containing fracture network and be collected in the lower part of this network, from where it can be recovered via recovery wells communicating with this lower part of the fracture network. It will be appreciated that extra oil will flow out of the unheated part of the fracture network into the heated part thereof if the pressure in the fracture network is reduced to a value lower than the value of the pressure originally prevailing therein.

The invention will now be described by way of example in more detail with reference to some embodiments thereof, which are shown in the accompanying drawing.

Figure 1 shows schematically a vertical section over a naturally fractured limestone formation, whereas Figure 2 shows the same formation in a later stage of the method carried out therein.

Since the scale of Figures 1 and 2 is too small to show details of the fracture network in the limestone formation, Figures 3—5 show on a larger scale than Figures 1 and 2, detail A (see Figures 1 and 2) of the formation during subsequent stages of the method. Figure 3 shows a vertical section over the fracture network and the limestone blocks containing viscous oil as originally present in the fractured limestone formation, whereas Figure 4 shows the same section as shown in Figure 3 but in the stage wherein the viscous oil has been displaced from the fracture network. Further, Figure 5 shows the same section as shown in Figures 3 and 4 but in the stage wherein the fracture

network substantially contains gas, and wherein oil is flowing out of the blocks into the fracture network under influence of gravity.

Finally, Figures 6 and 7 show a top view of well patterns that may be applied during a repeated application of the present invention in a formation.

The fractured limestone formation 1 shown in Figure 1 of the drawings is situated between cap rock 2 and base rock 3. Wells 4 and 5 extend through cap rock 2 and penetrate the formation 1. These wells are completed in a manner such that they communicate with the fracture network in the formation 1 over substantially the total height of this formation. An open hole completion may be suitable for this purpose, but it will be appreciated that the invention is not limited to the use of such a completion.

Details of the wells, as well as of any other equipment applied for carrying out the present method will not be shown, nor discussed since such details are all known per se to the expert in this field. The wells and the subsurface equipment is therefore shown schematically only.

The well 4 has a valve system 6 on top thereof and may communicate with a high pressure liquid pump 7 via a conduit 8 with valve 9, or with the outlet 10 of a heater 11. This outlet 10 can be closed off by a valve 12. The inlet 13 of the heater 11 communicates via the conduit 14 with the water outlet of a water/oil separator 15. This separator comprises an inlet 16 communicating with the wellhead of the well 5. The separator further comprises an oil outlet communicating with a conduit 17 leading to a (not shown) oil storage tank and a water outlet which is in communication with the conduit 14 leading to the inlet 13 of the heater 11. The wellhead of the well 5 can be closed off by a valve 18.

Details of the natural fracture network of formation 1 will be discussed hereinafter with reference to Figures 3—5.

Prior to carrying out the present invention, the fracture network 20 (see Figure 3) of the formation 1, as well as the pore space of the limestone blocks 21 that are surrounded by this fracture network 20, contain viscous oil of a viscosity over 500 centipoises. The specific gravity of this oil is about 1.1. Both properties are measured under formation conditions prior to carrying out the present method. The formation has a temperature of about 50 Centigrades and the pressure of the oil in the fracture network is about 350 atmospheres.

The first step of the method according to the invention is aimed to displace the viscous oil from the fracture network 20 in order to obtain a free passage for hot aqueous fluid that will subsequently be circulated through the fracture network 20 to increase the temperature of the limestone blocks 21 and the oil content thereof.

Viscous oil is displaced from that part of the fracture network situated between the wells 4 and 5 by injecting cold water into the formation 1 via the well 4. This water is supplied from an outside source of the pump 7 and after pressurizing led to the entry of the well 4 via conduit 8 and valves 6 and 9. The valve 12 is closed during the period that pump 7 is in operation. Viscous oil is thereby displaced through the fracture network 20 in the direction of the well 5 from which it is recovered. This oil is passed through the separator 15 and led to a (not shown) storage tank via the outlet 17 of the separator 15. Any water that is being produced together with the oil is separated from the oil in separator 15 and supplied to the inlet of pump 7 via a conduit (not shown).

The displacement of oil and the movement of the injected water through the formation 1 is schematically indicated by arrows 22 in Figure 1 of the drawing.

The flow resistance met by the oil in the region around the well 5 may be decreased by carrying out a thermal soak or a solvent soak around this well. This treatment may be repeated as many times as considered necessary. If desired, a well pump may be arranged in the well 5 to decrease the pressure in the fracture network around this well to a value lower than the value of the pressure originally prevailing in the fracture network. Hereby, an additional amount of oil will be recovered via the well 5. This additional oil originates from the expansion of oil present in the pore space of the limestone blocks, as well as from the inflow of oil out of parts of the fracture network that are situated at some distance from the well 5.

After that part of the fracture network 20 extending between the wells 4 and 5 has substantially been freed of viscous oil, the pump 7 is shut down and the valve 9 is closed off. Subsequently, hot aqueous fluid is circulated through the fracture network. As shown in Figure 4, the hot aqueous fluid 23 flows in the direction of arrows 23A through the fracture network 20 thereby heating the blocks 21 and the viscous oil contained in the pore space thereof. Hot water may be applied in this second step of the method as described by way of example with reference to Figures 1—5 of the drawing, if it is desired to prevent the inflow of oil from adjacent oil-filled parts of the fracture network, since by applying water, the injection pressure can be raised sufficiently high to maintain a pressure in

the water-filled part of the fracture network that is about equal to the pressure of about 350 atmospheres originally prevailing in the fracture network. It is observed however, that in case of limestone formations containing oil of extremely high viscosity, such as over 1,000 centipoises, hot water, or even steam at a pressure lower than the pressure in the oil-filled parts of the fracture system may be applied since this extremely high viscosity of the oil will inhibit this oil from flowing into that part of the fracture network through which hot aqueous fluid is being circulated for heating purposes.

However, application of the method according to the invention is not restricted to the circulation of hot aqueous fluid at a pressure in excess or equal to the original formation pressure. When applying a pressure that is lower than the pressure originally prevailing in the formation fluid, an extra amount of oil will become available for recovering. This oil originates from the pore space of the limestone blocks from which it is expulsed by expansion, and from the cold oil-filled parts of the fracture network. The pressure in the fracture network parts situated in the region around the well 5 may be reduced to a desired extent by operation of a well pump in this well 5.

The aqueous fluid that is being circulated through the formation 1 by means of a (not shown) pump that is incorporated in the conduit system extending between the valve 18 and the valve 6, is recovered via the well 5 after having given off the heat thereof to the formation 1. The direction of flow in this liquid through the formation 1 is indicated in Figure 1 by arrows 22 and in Figure 4 by arrows 23A. Via the water/oil separator 15, the aqueous fluid is subsequently passed to the heater 11. After heating, the hot aqueous fluid is reinjected into the formation via the well 4. Valve 12 has been opened for this purpose. If necessary, extra amounts of aqueous fluid may be supplied to the inlet 13 of the heater 11 from a (not shown) outside source.

The circulating hot aqueous fluid heats a portion of the formation 1 that is enclosed by the broken line 24. During heating of the block 21, the viscous oil contained in the pore space of these blocks will expand (under influence of the increase in temperature thereof as well as under influence of a reduction in pressure in case such pressure reduction is applied in zone 24) and oil will be expulsed from the pore space of the blocks 21 to enter the fracture network 20. Part of this oil will be recovered from the formation 1 together with the circulating aqueous fluid. This oil is separated from the aqueous fluid in the separator 15, and drained from the separator via the outlet 17 thereof towards a (not shown) storage tank.

A further expulsion of oil from the pore space of the blocks may take place by the vaporization of one or more of the components of the oil present in the pore space of these blocks. Gas or vapour bubbles formed by this vaporization, which results from the temperature increase of the oil (and also from a decrease of the pressure in the fracture network in case such pressure decrease is applied), will displace part of the oil from the pore space of the blocks.

After the region 24 of the formation 1 has been heated to a sufficient extent (which may take several years), the hot aqueous fluid is displaced from that part of the fracture network within the region 24 of the formation 1 by stopping the circulation of hot aqueous fluid, and injecting a non-condensable gas such as air into the fracture network. Thereto, the heater 11 and the separator 15 together with the conduit system belonging thereto is removed from the location to another (not shown) location where it will be operated to heat another portion of the formation 1, and the pump 7 is replaced by a gas compressor 7A (see Figure 2), which gas compressor is activated to compress air and inject this air via conduit 8, valves 9 and 6, and well 4 into the fracture network of the formation 1.

In the now following third stage of the recovery of oil, a substantial part of the recoverable oil will be produced. Since there exists a large difference between the specific gravities of the oil present in the blocks 21 and the air 25 (see Figure 5) present in the fracture network 20, the oil which has a reduced viscosity will now flow under influence of gravity out of the pore space of the blocks 21 and into the fracture network 20. Air will thereby enter into the upper part of the pore space of the blocks 21 and the air/oil levels 26 in the pore space of the blocks will gradually be lowered.

Any oil that is liberated from the pore space of the blocks 21 by gravity drainage, flows downwards through the fracture network (see arrows 27 in Figure 2 schematically indicating this downward movement) and collects in the lower part of the fracture system, where an air/oil interface 28 will be formed (see Figure 2 as well as Figure 5). Wells 4 and 5 have now been equipped to function as recovery wells and oil will be recovered from a level below the air/oil interface 28 via the wells 4 and 5. The flow of oil is through open valves 6, 18 and 29 and through conduits 30 and 31 towards the oil storage tank 32. Compressor 7A is shut down and valve 8 is closed during this oil recovery operation.

The oil is raised from the interface 28 to

the surface by (not shown) pumps that are installed in the wells 4 and 5 and/or by the pressure of the air present in the fracture network above the interface 28. The recovery rate of the oil is adjusted to a value which is sufficiently low to prevent gas breakthrough in the wells 4 and 5.

If necessary, or desired, the air pressure in the fracture network may be varied. Additonal air may be pumped into the network by closing valve 29, opening valve 8 and activating the compressor 7A. It will be appreciated that by maintaining a pressure in region 24 that is lower than the original fluid pressure in the formation 1, additional oil can be recovered from the formation 1. This additional oil results from the inflow of oil into region 24 from the non-heated parts of the fracture network that are situated outside region 24.

Cooling down of the region 24 of the formation 1 prior to the moment that the recoverable amount of oil has been drained from the blocks 21, may necessitate reheating of this region 24 of the formation 1. Thereto, the heater 11 and the separator 15 including the required conduits and valves are replaced and hot aqueous fluid is again circulated through the fracture network in the region 24 of the formation 1. After a sufficient increase in temperature of the region 24 has been obtained, the circulation of hot aqueous fluid is stopped and air (or another non-condensable gas) is reinjected to displace the aqueous fluid in the fracture network as explained earlier, in order to allow oil to be drained from the blocks 21 by the action of gravity. If necessary, this reheating procedure may be repeated more than once.

In an alternative method, the temperature in the region 24 may be maintained at a desired level during the gravity drainage period, by continuously suppling steam into the air-filled fracture network via a steam injection well. Also, this steam may be injected intermittently, either through a (not shown) well or through one or both of the wells 4 or 5. It will be appreciated that the well chosen for a temporary steam injection is then closed off for oil recovery.

In high pressure formations, a non-condensable gas such as air or natural gas is preferably chosen as a medium in the fracture network during the gravity drainage period, since such high pressure gas may often be available at a lower price than high-pressure steam. However, steam may be applied in low-pressure formations during the gravity drainage period. The injection rate of steam into the hot region 24 of the fracture network is then controlled to compensate the heat losses in this region. A pressure may be maintained in the hot region that is equal to the original pressure prevailing therein, or lower than this original pressure. In the latter case, additional oil will flow from the formation part outside region 24 into this region and be recovered therefrom.

After the recoverable amount of oil has been recovered from the region 24, the operation is stopped. Regions that are adjacent to the region 24 may subsequently be treated by the present method. This will be explained in somewhat more detail with reference to Figures 6 and 7 of the drawings, which figures show well patterns that may be applied for application of the present invention. The five-spot pattern shown in Figure 6 comprises a central well 33 which has the same function as well 5 in Figures 1 and 2, and four other wells 34 which have the same function as well 4 in Figures 1 and 2. The method as described hereinbefore with reference to Figures 1—5 may be carried out in the fractured formation which is penetrated by wells 33 and 34. This results in a hot region 35, from which the oil is recovered by gravity drainage. This oil is removed from the formation via one or more of the wells 33, 34. After all recoverable oil has been removed from region 35, the fracture network and the pore space of the block inside that region are filled up with cold water. Further, a new five-spot is formed (see Figure 7), which five-spot has a central well 36. Two of the wells 34 of the first five-spot are included in this new five-spot, and two other wells 37 are added. The method of the present invention as described with reference to Figures 1—5 is subsequently carried out in the second five-spot, without however using steam for heating purposes, since this would result in an inflow of cold water from that part of the fracture network that is situated within the first five-spot. The heat treatment of the region 38 surrounding the second five-spot renders oil inside the blocks movable, which oil is subsequently drained from these blocks by gravity action. Prior to this drainage, the fracture network inside the region 38 as well as inside the region 35 is freed from water by displacing this water to one or more of the wells by injecting a gas that is supplied to the fracture network via one or more of the other wells 33, 34, 36 and 37. Oil draining from the blocks is collected in the lower part of the fracture network extending over the regions 35 and 38 and recovered therefrom via one or more of the wells 33, 34, 36, 37 which are equipped as production wells for that purpose. Heat loses occurring in region 38 during the gravity drainage period may be compensated by a low-rate steam supply into the fracture network via one or more of

the wells located inside region 38. The flow rate of the steam through the fracture system is such that it has no influence on the movement of the oil that is flowing downwards through the fracture network to the lower part of this network.

It is observed that residual heat may found to be left in region 35 (see Figure 7) after the major amount of oil has been recovered therefrom. This heat may be recuperated by drilling the wells 37 of the second five-spot prior to injecting cold water into the first five-spot. After drilling wells 37, cold water is injected through those wells 34 that are not common with the second five-spot. This water flows through the hot region 35, thereby recuperating heat therefrom, which heat is subsequently introduced into the area covered by the second five-spot. At the same time, oil is displaced from this latter area by the hot water that flows from the fracture network in the region 35 into the fracture network located in the region 38. After all available heat has been recuperated from the region 35, the well 36 is drilled and region 38 is further heated by injecting hot water through this well 36 as has been described already hereinabove.

The flow direction of the fluid injected into the fracture network for removing the cold viscous oil from these fractures is not necessarily in the direction indicated by arrows 22 shown in Figure 1. If desired, the flow direction between injection and recovery wells may be reversed from time to time. The same applies for the flow direction of the hot aqueous fluid, which direction is indicated by arrows 23A in Figure 4.

Instead of cold water, hot water may be used to remove the viscous oil from the fracture network in the initial stage (that is during step a)) of the present method. The temperature of this hot water is higher than the original temperature of the formation. In another embodiment of the invention, gas (such as air, natural gas or steam) may be used for displacing the viscous oil from the fracture network. It will be appreciated that gas as displacement medium is in particular attractive for viscous fluids which have not an excessively high viscosity. The gas may be injected at a relatively high level in the fracture networks, whereas oil is recovered from a relatively low level in the fracture networks.

The fluids that are use in the present method may be treated chemically and/or physically prior to being injected into the formation in any one of the known manners suitable for preventing clogging of the formation, corrosion of tubing or heating units, flocculation of salts, etc., dissolved therein, scale formation in heating units, etc.

It is observed that an efficient distribution of the fluids over the fracture network may be promoted by a suitable selection of the locations of the injection and recovery wells. A number of well patterns are known for such purpose, and application of the invention is not restricted to any particular well pattern.

It will be understood that application of the method according to the invention is not restricted to formations of the type shown in Figures 1 and 2 and having a fracture network pattern as shown in Figures 3—5. Good results will also be obtained when carrying out the method according to the invention in fractured reservoirs of other configuration.

Also, the application of the method according to the invention is not restricted to the recovery of oil having a specific gravity of about 1.1 as described with reference to Figures 1—5 of the drawing. Oils with higher or lower specific gravities may be recovered with good results by using the present invention.

WHAT WE CLAIM IS:—

1. Method for recovering oil from a formation comprising permeable blocks surrounded by a natural fracture network, said formation containing oil in the fracture network and in the pore space of the blocks, said oil having a viscosity higher than 100 centipoises, the method including the steps of:

a) displacing oil from the fracture network in at least one region of the formation by injecting fluid into that region via a well communicating with the fracture network in that region;

b) circulating hot aqueous fluid through the fracture network in the said region to increase the temperature of the blocks in that region;

c) recovering oil via at least one production well during steps a) and b);

d) stopping the circulation of hot aqueous fluid and replacing this fluid in the fracture network by a gas under pressure;

e) allowing drainage of oil from the pore space of the blocks in said region into the gas-containing fractures in said region;

f) collecting drained oil in the lower part of the fractures in said region; and

g) recovering oil from this lower part of the said region via a well communicating with the fractures in said region.

2. Method according to claim 1, wherein the fluid injected in step a) is selected from the group of fluids consisting of gas, steam, water having a temperature higher than the original temperature of the formation, and

water having a temperature lower than the original temperature of the formation.

3. Method according to claim 1 or claim 2, wherein the hot aqueous fluid circulated in step b) substantially consists of water having a temperature higher than the original temperature of the formation.

4. Method according to claim 1 or claim 2, wherein the hot aqueous fluid circulated in step b) substantially consists of steam.

5. Method according to claim 1 or claim 2, wherein the hot aqueous fluid circulated in step b) substantially consists of a mixture of steam and water having a temperature higher than the original temperature of the formation.

6. Method according to any one of the claims 1—5, wherein the gas under pressure referred to in step d) comprises air that is kept stagnant in the fracture network in the said region during the step e).

7. Method according to any one of the claims 1—5, wherein the gas under pressure referred to in step d) comprises natural gas that is kept stagnant in the fracture network in said region during the step e).

8. Method according to claim 6 or claim 7, wherein steam is supplied to the gas-containing fractures during step e) to compensate heat losses in the said region.

9. Method according to any one of the claims 1—5, wherein the gas under pressure referred to in step d) substantially consists of steam.

10. Method according to claim 9, wherein additional steam is supplied to the steam-containing fractures during step e) to compensate heat losses.

11. Method according to any one of the preceding claims, wherein the formation is a limestone formation.

12. Method for recovering oil from a formation comprising permeable blocks surrounded by a natural fracture network, substantially as described in the specification with reference to Figures 1—5 and Figures 6 and 7 of the accompanying drawing.

13. Oil recovered by the method according to any one of the claims 1—12.

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1463444 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

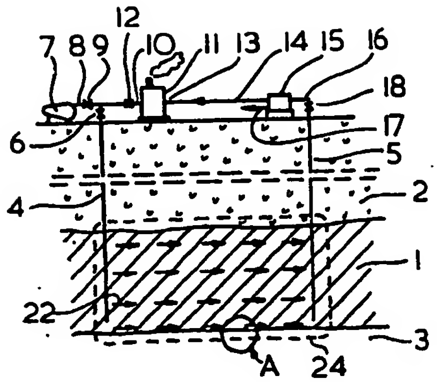

FIG.1

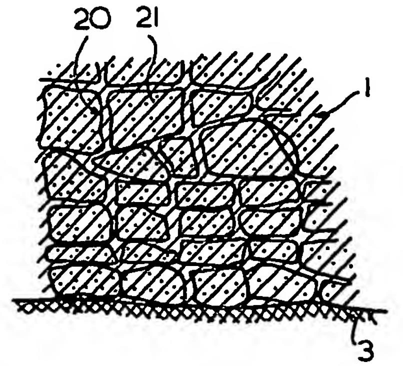

FIG.3

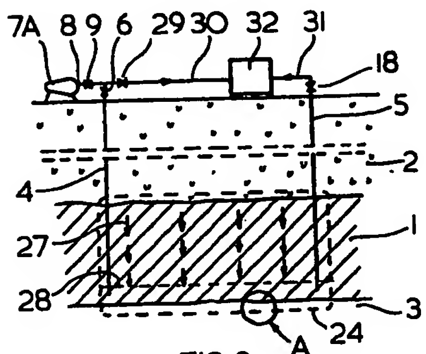

FIG.2

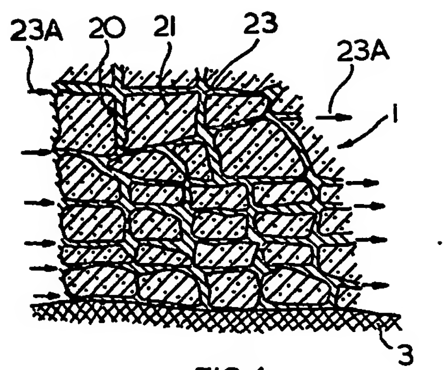

FIG.4

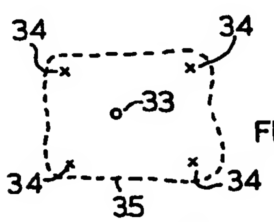

FIG.6

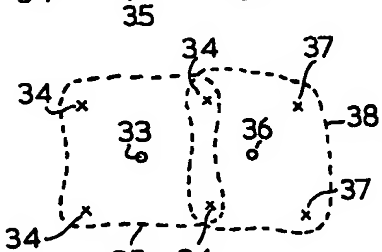

FIG.7

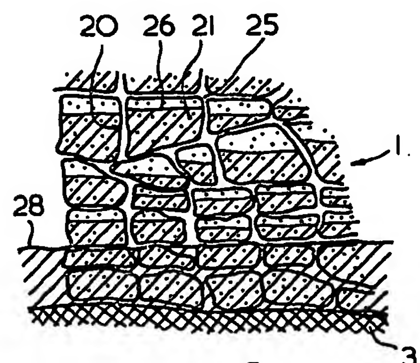

FIG.5